Direct and Spillover Effects of Middle School Vaccination Requirements

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ONLINE APPENDIX

This Appendix describes in greater detail the diseases under study.

1.1 Tetanus, Diphtheria, and Pertussis

Tetanus, diphtheria, and pertussis are all diseases caused by bacteria, and vaccination against them with a combination vaccine series (DTP or DTaP) has been routinely recommended for young children since the 1940s and 1950s. In early 2005 a new vaccine, Tdap (tetanus, diphtheria toxoid and acellular pertussis), was approved for use in adolescents and was recommended for preteens aged 11 or 12 as a booster for their DTP/DTaP series.[1]

Over the past 50 years there have been consistently high immunization rates for DTP/DTaP and, likely as a result, tetanus and diphtheria have become extremely rare in the United States.[2] That vaccine series has proven less effective

[1] Prior to the development of the Tdap vaccine, it had been recommended that adolescents receive a dose of the tetanus and diphtheria toxoids vaccine (Td) at age 11 or 12. This vaccine did not provide protection against pertussis, however. Protection under the acellular pertussis vaccines (DTaP and Tdap) wanes between 5-10 years after vaccination.

[2] Specifically, for the duration of our study period there have been 41 or fewer cases of tetanus (an infection that attacks the nervous system and causes muscle spasms) per year in the United States (approximately 0.01 cases per 100,000 population). Over that same time period that have been 2 or fewer cases of diphtheria (an infection that causes a thick covering in the back of the throat) per year. Due to the extremely low incidence of these diseases we are unable to credibly examine the effect of middle school vaccination mandates on the prevalence of diphtheria and tetanus.

against pertussis in the long-run, however, and so pertussis (or 'whooping cough') remains endemic in the United States.

Pertussis is a highly contagious respiratory disease,[3] and its symptoms include nose and throat inflammation and a violent cough. It is transmitted from person-to-person through respiratory secretions expelled while coughing or sneezing. The morbidity consequences of pertussis are most severe for infants under 6 months of age – they are hospitalized in 63 percent of cases (compared to 2 percent of infected adolescents) and account for 90 percent of the pertussis-related mortality (CDC 2002).

1.2 Meningococcal Disease

Meningococcal disease encapsulates the set of infections caused by the bacteria *Neisseria meningitidis* and includes infections of the lining of the brain and spinal cord (meningitis) and of the bloodstream (septicemia and bacteremia). There are numerous different serogroups (variations) of the bacteria; serogroups A, B, C, Y, and W are the most significant sources of meningococcal disease in the United States.[4] In our analysis we focus on the quadrivalent meningococcal conjugate vaccine (MCV4), which provides protection against serogroups A, C, Y, and W

[3] Secondary cases are estimated to occur at a rate of 80 percent among susceptible contacts in a household in which there has been a case of pertussis (CDC 2015a).

[4] The relative importance of each serogroup varies by age group: among children under the age of 5, serogroup B accounts for 60 percent of the cases of meningococcal disease, while for individuals over the age of 10, serogroups C, Y, and W cause 73 percent of the cases.

and has been routinely recommended for children age 11 or 12 since 2005.[5] Older teens are recommended to receive a second booster shot of MCV4 when they are 16 years old.

1.3 Human Papillomavirus (HPV)

HPV is the most common sexually transmitted infection in the United States: the CDC estimates that nearly all sexually active men and women will get HPV at some point in their lives. An estimated 79 million Americans are currently infected with HPV, with about 14 million people becoming newly infected each year. Most HPV infections are asymptomatic and typically resolve on their own. In some cases, however, infections persist and cause symptoms which can take years to develop. There are numerous types of HPV: low-risk types which can cause skin warts, and high risk types which cause the majority of the cancers of the cervix, vagina, penis, anus, mouth, and throat.[6] In the United States, rates of cervical cancer incidence and mortality are substantially higher among blacks and Hispanics (American Cancer Society 2015).[7]

[5] The first vaccine providing protection against serogroup B was not approved in the United States until late 2014.

[6] Nearly all cervical cancer (11,000 cases per year in the United States) is due to HPV, with two specific types (HPV16 and HPV18) accounting for over 65% of all cervical cancers, 55% of all cancers of the vagina, 49% of all cancers of the vulva, 48% of all cancers of the penis, 79% of all cancers of the anus, 79% of all cancers of the rectum, and 60% of all cancers of the throat (CDC 2016a).

[7] In the United States over the period 2008-2012, cervical cancer incidence rates were 44 percent higher for Hispanics and 41 percent higher for blacks, relative to whites. Over that same time period, mortality rates for Hispanics were 35 percent higher and 105 percent higher for blacks, relative to whites.

The first HPV vaccine was licensed for use in females in the United States in June 2006, and it was further approved for males in October 2009. This vaccine is a 3-dose series and provides protection against HPV types 6, 11, 16, and 18. The vaccine is only effective if it is given before an infection occurs, and so should be given prior to an individual's sexual debut. The ACIP currently recommends that all boys and girls initiate the HPV vaccine series between ages 11 and 12. Individuals who are not vaccinated by age 13 are recommended to receive catch-up vaccinations through age 21 (26) for men (women).

1.4 Seasonal influenza

Seasonal flu (common in fall and winter months) is an acute viral infection that can cause mild to severe illness with fever, cough, sore throat, runny nose, muscle aches, fatigue, vomiting, and/or diarrhea. It is highly contagious; individuals can infect other people up to an entire day before and up to a week after symptoms develop. Young children, the elderly, and people with compromised immune systems are at particularly high risk for seasonal flu complications. The flu vaccine varies from season to season with respect to the particular strains of the influenza virus that it protects against. The annual influenza vaccine was routinely recommended for children over the age of 6 months for the first time in 2010; in the subsequent flu season less than half of youths between 6 months and 17 years of age received the influenza vaccine.

Each year millions of people in the United States become ill from the seasonal flu, hundreds of thousands are hospitalized, and tens of thousands die.

Appendix Figure 1:
Example of State Department of Health Flyer for Middle School Vaccination Requirement: Wisconsin

Fact Sheet for Parents

Tdap Requirements for Middle and High School Students

The Wisconsin Student Immunization law requires that all students entering the 6th grade receive a dose of Tdap vaccine. To be compliant with the school law, parents must provide their child's school with proof of immunization or claim a waiver.

1. **What is Tdap?**
   Tdap is a vaccine that protects against Tetanus, Diphtheria, and Pertussis (whooping cough).

2. **What grades are affected and what vaccine is required?**
   All students entering grades 6 through 12 must have one dose of Tdap.

3. **What do parents need to do?**
   Have your child vaccinated with Tdap vaccine if he or she has not already received the vaccine. Record the date of the immunization in the appropriate box on the enclosed Student Immunization Record, sign the form and return it to your child's school. Be sure to add the Tdap vaccination date to the permanent immunization record you keep for your child. In the future, your child may need to give these dates to other schools, colleges or employers.
   To claim a waiver for health, religious or personal conviction reasons, follow the instructions on the Student Immunization Record and return the signed form to your child's school.

4. **Are there exceptions to the Tdap vaccine requirements?**
   Yes. If your child has received a tetanus-containing vaccine (such as Td) in the five years before he/she enters the grade in which it is required, your child is compliant and is not required to receive a Tdap. Check the box marked "Td" on the Student Immunization Record, enter the date it was received and return the signed form to school.

5. **Once my child meets the Tdap requirement will he or she need to get another dose in a different grade?**
   No. Tdap is a one-time requirement. Once a child meets the vaccine requirement for the grade to which the requirement applies, no further doses are required. In other words, a student who receives Tdap before starting 6th grade does not need any more doses. If a child received a dose of Td vaccine within 5 years of entering 6th grade, that child has met the Tdap requirement (even though s/he has not actually received Tdap vaccine) and will not be required to receive Tdap vaccine now or in a future grade.

Appendix Figure 1, continued: Example of State Department of Health Flyer for Middle School Vaccination Requirement: Wisconsin

6. If my child already had pertussis (whooping cough) disease, should he or she still get the Tdap vaccine?

A history of pertussis disease is not an exception to the Tdap requirement. Children who have had pertussis should still receive Tdap because the length of protection provided by the disease is unknown and because the diagnosis can be difficult to confirm in some instances.

7. Where can I get Tdap vaccine for my child?

Tdap is available from your child's medical provider, local health departments and some pharmacies. Please have your child immunized well in advance of school opening to avoid the late summer rush as doctor's offices and immunization clinics.

8. Why is Tdap required?

Pertussis is a serious disease. It is easily passed from person-to-person and can cause outbreaks in schools. Wisconsin has experienced two state-wide pertussis outbreaks in the past 10 years. People who are ill with pertussis must stay home from work or school for at least five days. Studies have shown that the protection gained from the DTP/DTaP vaccines received as a young child begins to decline 5 to 10 years after vaccination; the Tdap vaccine will boost that immunity and help protect your adolescent from pertussis.

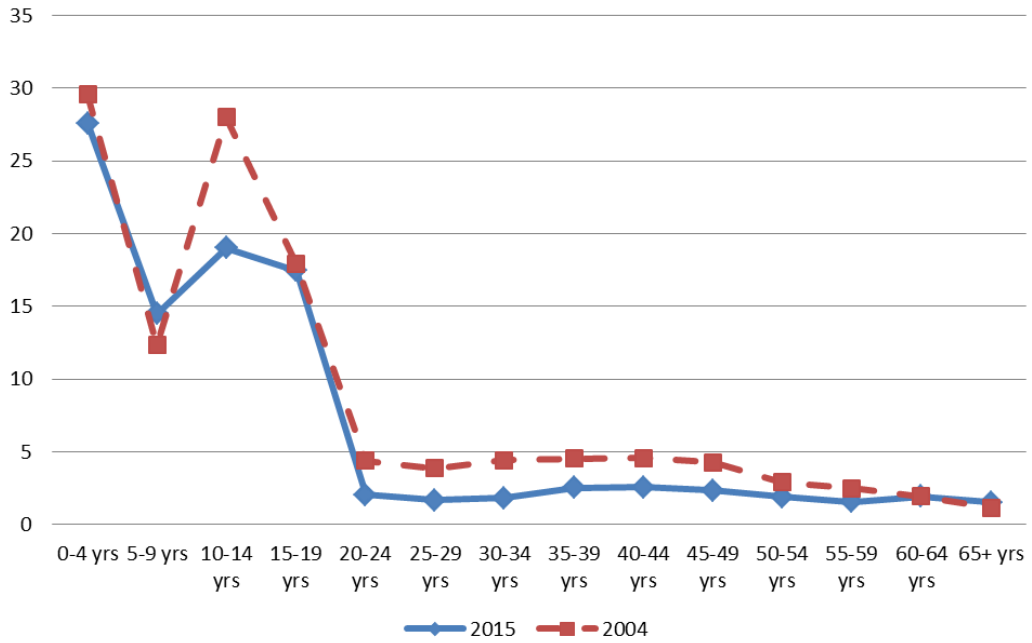
9. Are there any other vaccines that are recommended for my adolescent?

Yes. There are three other vaccines that are routinely recommended for teens. The Human Papillomavirus Vaccine (HPV) vaccine protects against a virus that is a common cause of cancer. The meningococcal conjugate vaccine protects against meningococcal disease (meningitis), and an annual influenza vaccine is recommended for everyone 6 months of age and older.

10. Where can I get more information?

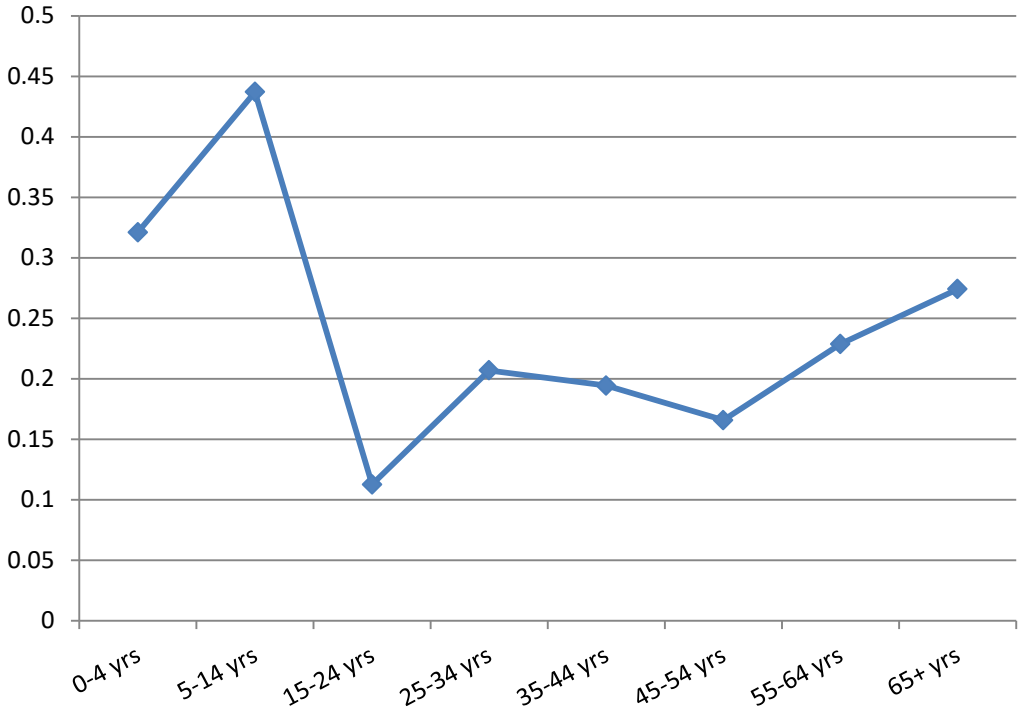
- Center for Disease Control (CDC): http://www.cdc.gov/vaccines/vpd-vac/pertussis/default.htm
- Wisconsin Immunization Program: https://www.dhs.wisconsin.gov/immunization/pertussis.htm
- Your child's medical provider or local health department

Appendix Figure 2:
Age Profile of Pertussis Incidence, 2004 and 2015



Notes: Each point represents the age-group specific pertussis rate per 100,000 population, calculated at the national level using CDC data.

Appendix Figure 3:
Estimated Effect Sizes of Direct and Spillover Effects of Tdap Mandates on Pertussis Incidence Across the Life Course (relative to 2004)



Notes: Each point is equal to the coefficient on the Tdap mandate indicator variable from a regression in which the outcome variable is the rate of disease incidence for the given age group, divided by the age-group specific disease incidence rate in the base year of 2004. These values are then multiplied by negative one, in order to obtain the estimated percent reduction in disease incidence. All coefficients are from specifications that include the full set of state policy controls as described in the notes to Table 1and state-specific linear time trends.

Appendix Table 1:
Descriptive Statistics, NIS-Teen 2008-2013 and CDC 2001-2015

	(1) Full sample	(2) Individuals in states that had a Tdap mandate by 2013	(3) Individuals in states that did not have a Tdap mandate by 2013
Child's vaccination rates, by age 13			
Tdap Booster	0.449	0.454	0.379
Meningococcal Vaccine	0.357	0.360	0.312
Initiation of HPV series	0.236	0.238	0.204
Completion of HPV series	0.099	0.100	0.079
Influenza vaccine (past 3 years)	0.122	0.121	0.137
Child's characteristics			
Female	0.488	0.488	0.490
Hispanic	0.203	0.212	0.079
White	0.576	0.577	0.554
Black	0.142	0.134	0.251
Other ethnicity	0.079	0.076	0.116
11-12 year old check-up	0.897	0.898	0.888
Mother's characteristics			
Less than high school	0.140	0.143	0.099
High school	0.261	0.260	0.272
Some college	0.259	0.259	0.256
College degree or above	0.340	0.338	0.372
Married	0.696	0.697	0.684
Age: <35 yrs	0.094	0.093	0.102
Age: 35-44 yrs	0.455	0.455	0.451
Age: 45+ yrs	0.451	0.452	0.447
Morbidity Rates per 100,000 pop., CDC data			
Pertussis, population rate	6.89	6.85	9.35
Pertussis, 5-14 year old rate	18.6	18.4	29.8
NIS-Teen Observations	116304	100899	15405
CDC Observations	763	690	73

Notes: All values are weighted means calculated by the authors from NIS-Teen 2008-2013 data, using provided sample weights, and CDC 2001-2015 data, weighted by state population. The mean rates of HPV vaccine series initiation and completion are calculated using the sample of females who were aged 13 between 2007-2013 and males who were aged 13 between 2010-2013.

Appendix Table 2:
Event Study Estimates of the Direct Effect of Middle School Vaccination Requirements, NIS-Teen 2008-2013

	(1)	(2)
	1 dose Tdap booster	1 dose Tdap booster
Sample mean	0.449	0.449
Δ (final year - base year mean)	*0.814*	*0.814*
6+ years before Tdap mandate	0.00831 (0.0375)	-0.122 (0.0755)
5 years before Tdap mandate	-0.0163 (0.0289)	-0.137 (0.0614)**
4 years before Tdap mandate	-0.0111 (0.0228)	-0.0975 (0.0427)**
3 years before Tdap mandate	0.00591 (0.0145)	-0.0613 (0.0298)**
2 years before Tdap mandate	0.0104 (0.0120)	-0.0280 (0.0176)
Year of Tdap mandate	0.0508 (0.0118)***	0.0799 (0.0156)***
1 year after Tdap mandate	0.151 (0.0197)***	0.204 (0.0342)***
2 years after Tdap mandate	0.212 (0.0186)***	0.290 (0.0422)***
3 years after Tdap mandate	0.238 (0.0265)***	0.351 (0.0512)***
4 years after Tdap mandate	0.211 (0.0336)***	0.351 (0.0732)***
5+ years after Tdap mandate	0.249 (0.0285)***	0.399 (0.0755)***
N	116304	116304
R-Squared	0.337	0.339
Other policy controls?	Y	Y
Other state/time varying Xs?	Y	Y
State and year fixed effects?	Y	Y
Linear state trends?	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. See notes to Table 1 for details on the specification and control variables.

Appendix Table 3:
Estimates of Non-linear Effects of Mandates Based on Prior Disease Incidence, CDC Data 2001-2015

	(1) Pertussis rate	(2) Pertussis rate	(3) Pertussis rate	(4) Pertussis rate
Sample mean	6.889	6.889	6.889	6.889
Δ (2015 mean - 2001 mean)	*3.792*	*3.792*	*3.792*	*3.792*
Lagged pertussis rate	0.0719	-0.00980	0.0718*	-0.0206
	(0.0439)	(0.0344)	(0.0419)	(0.0350)
Tdap mandate	-2.608*	-2.347	-1.000	0.378
	(1.376)	(1.632)	(1.362)	(1.177)
Tdap mandate * 2004 pertussis rate	0.0479	0.0162	---	---
	(0.0470)	(0.0592)		
Tdap mandate * Lagged pertussis rate	---	---	-0.137**	-0.299**
			(0.0570)	(0.122)
N	763	763	763	763
R-Squared	0.440	0.486	0.440	0.490
Linear state trends?	N	Y	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. See notes to Table 1 for details on the specification and control variables.

Appendix Table 4:
Event Study Estimates of the Direct Effect of Middle School Vaccination Requirements, CDC Data 2001-2015

	(1) Pertussis Morbidity	(2) Pertussis Morbidity
Sample mean	6.889	6.889
Δ (2015 mean - 2001 mean)	*3.792*	*3.792*
6+ years before Tdap mandate	-2.404 (2.489)	-5.304 (2.715)*
5 years before Tdap mandate	-2.825 (2.016)	-4.181 (2.043)**
4 years before Tdap mandate	-0.776 (3.159)	-1.769 (2.860)
3 years before Tdap mandate	-3.039 (2.194)	-3.371 (1.973)*
2 years before Tdap mandate	-3.976 (2.386)	-3.846 (2.288)*
Year of Tdap mandate	-3.656 (1.677)**	-2.203 (1.384)
1 year after Tdap mandate	-6.701 (3.784)*	-5.146 (3.361)
2 years after Tdap mandate	-5.158 (2.341)**	-2.545 (2.190)
3 years after Tdap mandate	-1.382 (1.925)	1.767 (2.501)
4 years after Tdap mandate	-0.190 (4.125)	4.247 (4.320)
5+ years after Tdap mandate	-2.761 (3.640)	3.525 (4.643)
N	763	763
R-Squared	0.468	0.518
Other policy controls?	Y	Y
Other state/time varying Xs?	Y	Y
State and year fixed effects?	Y	Y
Linear state trends?	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. See notes to Table 1 for details on the specification and control variables.

Appendix Table 5:
Tdap Mandates Had No Effects on Diseases Other than Pertussis

	(1) Pertussis	(2) Hepatitis A	(3) Hepatitis B	(4) Mening-ococcal Disease	(5) Tuberculosis	(6) Measles	(7) Lyme Disease	(8) Salmon-ellosis
Sample mean	6.889	1.261	2.130	0.361	4.083	0.0441	9.443	12.25
Tdap mandate	-2.241*	0.0489	0.278	-0.0259	0.000313	0.111	-0.617	-0.563
	(1.262)	(0.105)	(0.553)	(0.0211)	(0.0773)	(0.0698)	(1.530)	(1.221)
Sample years:	2001-2015	2001-2015	2001-2015	2001-2015	2001-2015	2001-2015	2001-2015	2001-2015
Observations	763	760	748	764	764	763	749	745
R-Squared	0.439	0.751	0.601	0.834	0.969	0.211	0.862	0.710

* significant at 10%; ** significant at 5%; *** significant at 1%. Sample means are calculated over the full period. Results are estimated using disease incidence data from the CDC and are weighted by state population. The dependent variable is the number of reported cases of the disease per 100,000 population. These models include controls for state mandates for insurance coverage of well-child visits and vaccines; all child care/school vaccination mandates; state HPV and MCV policies; lagged pertussis incidence; state children's Medicaid/CHIP income eligibility thresholds; state unemployment rates; state demographic characteristics (fraction black, Hispanic, and other races, fraction of individuals with high school degree and with some college or more, and fraction below the federal poverty level); and state and year fixed effects. Standard errors are clustered at the state level.

Appendix Table 6:
Effects of mandates on Tdap vaccination of 7-9 and 14-17 year olds in NIS-Teen
NIS-Teen 2008-2013

	All states		Only states that did not mandate receipt for >13 year olds			
	(1)	(2)	(3)	(4)	(5)	(6)
	1 dose Td-containing vaccine, 7-9 year olds	1 dose Td-containing vaccine, 7-9 year olds	1 dose Td-containing vaccine, 14-15 year olds	1 dose Td-containing vaccine, 14-15 year olds	1 dose Td-containing vaccine, 16-17 year olds	1 dose Td-containing vaccine, 16-17 year olds
Sample mean	0.0232	0.0232	0.141	0.141	0.0419	0.0419
Δ(final-base year mean)	0.005	0.005	-0.255	-0.255	-0.183	-0.183
Tdap mandate	0.00436	0.000424	-0.0158	0.00114	0.0134**	0.0233***
	(0.00399)	(0.00492)	(0.0147)	(0.0172)	(0.00626)	(0.00801)
R-Squared	.0232	.0232	0.123	0.131	0.0906	0.0952
N	59981	59981	91041	91041	82060	82060
Individual characteristics?	Y	Y	Y	Y	Y	Y
Other policy controls?	Y	Y	Y	Y	Y	Y
Other state/time varying Xs?	Y	Y	Y	Y	Y	Y
State and year fixed effects?	Y	Y	Y	Y	Y	Y
Linear state trends	N	Y	N	Y	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. Sample means are calculated over the full period. Results are from linear probability models and use NIS-Teen sampling weights. All models include controls for individual demographic characteristics (age at observation fixed effects, gender, race, number of children in the household, and mother's age, education level, and marital status); state, and birth cohort fixed effects; state mandates for insurance coverage of well-child visits and vaccines; state college and high school immunization and education requirements for MCV; state HPV policies (see text for details); state immunization mandates for child care/kindergarten entry; lagged state pertussis and meningococcal disease incidence; state children's Medicaid/CHIP income eligibility thresholds; state unemployment rates; and state demographic characteristics (fraction black, Hispanic, and other races, fraction of individuals with high school degree and with some college or more, and fraction below the federal poverty level). Even numbered columns also include linear state trends. Standard errors are clustered at the state level.

Appendix Table 7:
Cross-Age Morbidity Effects Among Infants Were Disease-Related, Not Vaccination-Related (i.e., Consistent with Herd Immunity Effects, not Behavioral Spillover Effects)
NIS 2003-2015, 19-35 month olds

	(1) Up-to-date, 4 doses of DTaP	(2) Up-to-date, 4 doses of DTaP other children in Household	(3) Up-to-date, 4 doses of DTaP, no other children in Household
Sample mean	0.846	0.834	0.882
Δ (2015 mean - 2003 mean)	*0.001*	*0.000*	*-0.003*
Tdap Mandate for Middle School Entry	-0.00706	-0.00487	-0.0124
	(0.00479)	(0.00637)	(0.00793)
R-squared	0.0420	0.0445	0.0289
N	212202	159157	53045

* significant at 10%; ** significant at 5%; *** significant at 1%. Results are from linear probability models and use NIS sampling weights. All models include controls for individual demographic characteristics (age at observation fixed effects, gender, race, number of children in the household, and mother's age, education level, and marital status); state and year fixed effects; state mandates for insurance coverage of well-child visits and vaccines; child care and school vaccination mandates; state HPV policies; lagged state pertussis and meningococcal disease incidence; state children's Medicaid/CHIP income eligibility thresholds; state unemployment rates; and state demographic characteristics (fraction black, Hispanic, and other races, fraction of individuals with high school degree and with some college or more, and fraction below the federal poverty level). All models also include linear state trends. Standard errors are clustered at the state level.

Appendix Table 8:
Event Study Estimates of the Spillover Effects of Middle School Vaccination Requirements for Tdap, NIS-Teen 2008-2013

	(1) 1 dose MCV vaccination	(2) 1 dose MCV vaccination	(3) 1 dose HPV Vaccine	(4) 1 dose HPV Vaccine	(5) Completed HPV Vaccine	(6) Completed HPV Vaccine
Sample mean	0.357	0.357	0.236	0.236	0.0987	0.0987
Δ (final year mean - base year mean)	*0.724*	*0.724*	*0.306*	*0.306*	*0.139*	*0.139*
Years relative to Tdap mandate:						
6+ years before	-0.0725 (0.0292)**	-0.0881 (0.0412)**	-0.117 (0.0460)**	-0.112 (0.146)	-0.00172 (0.0262)	0.0442 (0.0939)
5 years before	-0.0792 (0.024)***	-0.109 (0.0345)***	-0.102 (0.0359)***	-0.110 (0.112)	-0.0214 (0.0194)	0.00906 (0.0729)
4 years before	-0.0396 (0.0204)*	-0.0600 (0.0259)**	-0.0921 (0.0228)***	-0.0744 (0.0786)	-0.0282 (0.0142)*	0.00822 (0.0539)
3 years before	-0.0511 (0.018)***	-0.0744 (0.021)***	-0.0682 (0.0177)***	-0.0655 (0.0506)	-0.0170 (0.0144)	0.00168 (0.0382)
2 years before	-0.0079 (0.0126)	-0.0249 (0.0128)*	-0.0335 (0.0136)**	-0.0446 (0.0256)*	-0.0161 (0.00880)*	-0.0160 (0.0190)
Year of	0.0282 (0.0104)***	0.0419 (0.0142)***	0.0573 (0.0129)***	0.0686 (0.0229)***	0.0260 (0.0126)**	0.0288 (0.0182)
1 year after	0.0482 (0.0183)**	0.0752 (0.0227)***	0.108 (0.0186)***	0.142 (0.0364)***	0.0507 (0.0140)***	0.0624 (0.0284)**
2 years after	0.0972 (0.0176)***	0.140 (0.0262)***	0.142 (0.0319)***	0.198 (0.0531)***	0.0492 (0.0198)**	0.0623 (0.0392)
3 years after	0.109 (0.0224)***	0.176 (0.0347)***	0.152 (0.0330)***	0.244 (0.0652)***	0.0615 (0.0223)***	0.0885 (0.0541)
4 years after	0.0949 (0.0306)***	0.191 (0.0450)***	0.171 (0.0449)***	0.284 (0.0747)***	0.0634 (0.0257)**	0.0888 (0.0617)
5+ years after	0.143 (0.0327)***	0.250 (0.0530)***	0.187 (0.0489)***	0.348 (0.0845)***	0.0649 (0.0306)**	0.104 (0.0718)
N	116304	116304	57133	57133	57133	57133
R-Squared	0.287	0.290	0.112	0.114	0.066	0.067
Linear trends?	N	Y	N	Y	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. See notes to Table 1 for details on the specification and control variables. Columns 3-6 are restricted to females who were aged 13 between 2007-2013 and males who were aged 13 between 2010-2013. All models include the full set of controls, columns 2, 4, and 6 additionally include state linear trends. Sample means are calculated using the base year of data.

Appendix Table 9:
Other Ways to Measure Cross-Vaccine Spillover Effects of Tdap Mandates: Combinations of Outcomes, NIS-Teen 2008-2013

	(1)	(2)	(3)	(4)	(5)
	Had 1 dose Tdap AND 1 dose MCV	Had 1 dose Tdap AND Initiated HPV vaccine	Had 1 dose Tdap AND Completed HPV vaccine	Had 1 dose Tdap AND 1 dose MCV AND Initiated HPV vaccine	Had 1 dose Tdap AND 1 dose MCV AND Completed HPV vaccine
Sample mean	0.303	0.170	0.076	0.150	0.068
Δ (final year mean - base year mean)	*0.693*	*0.203*	*0.074*	*0.212*	*0.082*
Tdap Mandate for Middle School Entry	0.0458***	0.0445**	0.0505***	0.0479***	0.0461***
	(0.0123)	(0.0171)	(0.0163)	(0.0153)	(0.0136)
R-squared	0.297	0.161	0.082	0.145	0.073
N	116304	58474	58474	58474	58474

* significant at 10%; ** significant at 5%; *** significant at 1%. See notes to Table 1 for details on the specification and control variables. Columns 2-5 are restricted to females who were aged 13 between 2007-2013 and males who were aged 13 between 2011-2013. All models include the full set of controls, including linear state trends.

Appendix Table 10:
Main Vaccination Results Are Robust to Including NIS-Teen 2014 and 2015 Sample Waves, NIS-Teen 2008-2015

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	1 dose Tdap booster	1 dose Tdap booster	1 dose MCV	1 dose MCV	Initiated HPV vaccine	Initiated HPV vaccine	Completed HPV vaccine	Completed HPV vaccine
Sample mean	0.530	0.530	0.438	0.438	0.265	0.265	0.111	0.111
Δ (final year mean - base year mean)	*0.824*	*0.824*	*0.773*	*0.773*	*0.431*	*0.431*	*0.203*	*0.203*
Tdap Mandate for Middle School Entry	0.137***	0.154***	0.0330**	0.0366**	0.0331***	0.0165	0.0180***	0.0156**
	(0.0138)	(0.0154)	(0.0137)	(0.0147)	(0.0119)	(0.0130)	(0.00520)	(0.00716)
R-squared	0.339	0.341	0.299	0.301	0.117	0.118	0.0601	0.0612
N	158268	158268	158268	158268	97233	97233	97233	97233
Linear state trends?	N	Y	N	Y	N	Y	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. See notes to Table 1 for details on the specification and control variables. Columns 5-8 are restricted to females who were age 13 between 2007-2015 and males who were age 13 between 2011-2015.

Appendix Table 11:
Other Ways to Measure Cross-Vaccine Spillover Effects of Tdap Mandates: the Role of ACIP Recommendations, NIS-Teen 2008-2013

	(1) 1 dose MCV	(2) Initiated HPV vaccine	(3) Completed HPV vaccine	(4) Had seasonal influenza vaccine, age 10-13
Sample mean	0.357	0.236	0.099	0.122
Δ (final year mean - base year mean)	*0.724*	*0.306*	*0.139*	*0.436*
Tdap Mandate for Middle School Entry	-0.0482	0.00147	0.0199	0.00494
	(0.0317)	(0.0263)	(0.0142)	(0.00670)
Tdap Mandate × ACIP recommendation for MCV	0.0769***			
	(0.0246)			
Tdap Mandate × ACIP recommendation for HPV		0.0475**	0.0157	
		(0.0197)	(0.0117)	
Tdap Mandate × ACIP recommendation for Flu				0.0247*
				(0.0139)
R-squared	0.289	0.114	0.067	0.175
N	116304	57133	57133	116304

* significant at 10%; ** significant at 5%; *** significant at 1%. See notes to Table 1 for details on the specification and control variables. Columns 2-3 are restricted to females who were aged 13 between 2007-2013 and males who were aged 13 between 2011-2013. All models include the full set of controls, including linear state trends.

Appendix Table 12:
Effects of Middle School Tdap Vaccination Requirements for Table 5 Samples, NIS-Teen 2008-2013
Each entry is the coefficient on the Tdap mandate

	(1) 1 dose Tdap	(2) 1 dose Tdap	(3) 1 dose MCV	(4) 1 dose MCV	(5) Initiated HPV vaccine	(6) Initiated HPV vaccine	(7) Completed HPV vaccine	(8) Completed HPV vaccine
1. 'Ever heard of HPV' sample	0.0811**	0.0720*	0.0767**	0.0145	0.0574	-0.0165	0.0733***	0.0346
	(0.0356)	(0.0381)	(0.0344)	(0.0729)	(0.0486)	(0.0504)	(0.0196)	(0.0275)
2. 'Ever heard of HPV shot' sample	0.0816**	0.0713*	0.0803**	0.0170	0.0564	-0.0235	0.0754***	0.0347
	(0.0355)	(0.0369)	(0.0337)	(0.0720)	(0.0481)	(0.0502)	(0.0194)	(0.0271)
3. 'Doctor recommended HPV vaccine' sample	0.135***	0.120***	0.0176	0.00520	0.0654***	0.0122	0.0430***	0.0450**
	(0.0221)	(0.0356)	(0.0182)	(0.0314)	(0.0233)	(0.0369)	(0.0119)	(0.0197)
4. 'Had an 11-12 yo well child visit' sample	0.129***	0.130***	0.0232	-0.0136	0.0528***	0.0117	0.0354***	0.0404***
	(0.0228)	(0.0304)	(0.0207)	(0.0266)	(0.0187)	(0.0223)	(0.00904)	(0.0131)
Linear state trends?	N	Y	N	Y	N	Y	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. The sample in row 1 corresponds to the sample in columns (1) and (2) of table 5; the sample in row 2 corresponds to the sample in columns (3) and (4) in table 5; the sample in row 3 corresponds to the sample in columns (5) and (6) of table 5; the sample in row 4 corresponds to the sample in columns (7) and (8) in table 5. See notes to Table 1 for details on the specification and control variables.

Appendix Table 13:
Event Study Estimates of Google Trends Analyses, 2005-2013

	(1) Relative Google search popularity for 'Tdap'	(2) Relative Google search popularity for 'Tdap'	(3) Relative Google search popularity of the 'Meningococcal vaccine' topic	(4) Relative Google search popularity of the 'Meningococcal vaccine' topic	(5) Relative Google search popularity for 'hpv'	(6) Relative Google search popularity for 'hpv'
Sample mean	30.82	30.82	56.63	56.63	43.83	43.83
Δ (final - base yr mean)	*25.54*	*25.54*	*-30.98*	*-30.98*	*1.18*	*1.18*
Relative to Tdap mandate:						
6+ years before	-6.755 (5.879)	-7.621 (7.691)	-11.42 (3.793)***	-11.98 (8.502)	-0.00278 (1.519)	1.342 (4.433)
5 years before	-7.857 (4.244)*	-4.805 (5.650)	-8.185 (3.297)**	-10.12 (6.617)	-1.828 (1.207)	0.492 (3.504)
4 years before	-3.139 (3.205)	-0.875 (4.665)	-3.806 (2.629)	-4.822 (4.873)	0.377 (0.993)	1.999 (2.752)
3 years before	0.429 (2.635)	0.787 (3.402)	1.898 (2.168)	-0.256 (3.287)	0.856 (1.376)	1.378 (2.034)
2 years before	-0.245 (1.128)	1.033 (1.794)	-1.323 (1.368)	-1.962 (2.002)	-0.0609 (1.264)	0.379 (1.596)
Year of	12.34 (3.285)***	10.60 (2.787)***	4.881 (1.876)**	6.250 (2.393)**	2.271 (1.417)	1.439 (1.254)
1 year after	10.25 (2.669)***	4.102 (2.904)	7.484 (2.746)***	7.636 (3.354)**	2.224 (1.618)	1.487 (1.710)
2 years after	10.81 (3.108)***	3.287 (4.029)	9.647 (3.404)***	10.94 (4.576)**	2.744 (2.035)	1.755 (2.256)
3 years after	16.58 (4.432)***	4.804 (5.465)	12.15 (4.792)**	13.97 (6.067)**	1.438 (2.463)	0.985 (2.970)
4 years after	18.98 (5.381)***	1.964 (7.309)	14.30 (5.825)**	13.75 (7.262)*	2.365 (2.538)	1.166 (3.561)
5 years after	22.68 (6.324)***	1.877 (8.716)	15.93 (5.277)***	14.75 (7.498)*	2.041 (2.756)	0.596 (4.043)
6+ years after	31.14 (7.834)***	2.317 (11.64)	20.05 (6.083)***	16.02 (8.889)*	1.673 (2.684)	-1.405 (4.430)
N	4845	4845	4825	4825	5508	5508
R-Squared	0.683	0.742	0.625	0.663	0.795	0.806
Linear trends?	N	Y	N	Y	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. The outcome variable is a measure of the popularity of a given search term or topic, in which, for each state, the month of peak search volume is normalized to 100. All models include the state policy controls and state demographics as described in the notes to Table 1 as well as fixed effects for each state and for each month-year. Columns 2, 4, and 6 also include linear state trends.

ADDITIONAL RESULTS REFERENCED IN THE ARTICLE

Appendix Table 14:
Effects of mandates on Tdap vaccination of adults in BRFSS (vaccine spillover effects)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	All adults 18+	18-64 year olds	18-24 year olds	25-34 year olds	35-44 year olds	45-54 year olds	55-64 year olds	65+ year olds
Sample mean	0.200	0.216	0.265	0.255	0.222	0.183	0.169	0.130
Tdap Mandate for Middle School Entry	0.0118***	0.0107***	0.0111	-0.0278**	-0.00455	0.0301*	0.0303**	0.0168
	[0.001]	[0.006]	[0.488]	[0.034]	[0.690]	[0.098]	[0.022]	[0.384]
R-Squared	0.0561	0.0548	0.0494	0.0788	0.0608	0.0416	0.0359	0.0326
N	253573	167149	12161	23861	29849	43100	58178	86424

* significant at 10%; ** significant at 5%; *** significant at 1%. Outcome variable is an indicator variable that is equal to one if the respondent has had a Tdap vaccine since 2005. Sample includes the following state/years: Arizona 2012, 2013, 2016; Georgia 2013, 2014, 2016; Minnesota 2012, 2013, 2016; Mississippi 2013-2016; Missouri 2013, 2015, 2016; Rhode Island 2013, 2014, 2016; South Carolina 2013, 2015, 2016; Tennessee 2013, 2014, 2016; Texas 2012, 2013, 2016; Vermont 2012-2014, 2016; Virginia 2012-2016; West Virginia 2013, 2015, 2016. Over this period, three states adopted mandates (Georgia in 2014, Minnesota in 2014, and South Carolina in 2013. Sample means are calculated over the full period. Results are from linear probability models and use the BRFSS sampling weights. All models include controls for individual demographic characteristics (age, age squared, gender, race, education level, and marital status); state, year of survey, and month fixed effects; state mandates for insurance coverage of well-child visits and vaccines; state college and high school immunization and education requirements for MCV; state HPV policies (see text for details); state immunization mandates for child care/kindergarten entry; lagged state pertussis and meningococcal disease incidence; state children's Medicaid/CHIP income eligibility thresholds; state unemployment rates; and state demographic characteristics (fraction black, Hispanic, and other races, fraction of individuals with high school degree and with some college or more, and fraction below the federal poverty level). P-values are presented in brackets. To address the small number of clusters, p-values are estimated using the wild bootstrap procedure proposed by Cameron, Gelbach, and Miller (2008) and implemented using the Stata command *cgmwildboot.*

Appendix Table 15:
Testing for Heterogeneous Effects by Insurance Status and Presence of Immunization Insurance Mandate

	(1)	(2)	(3)	(4)	(5)	(6)
	1 dose Tdap booster, 13 year olds, private insurance	1 dose Tdap booster, 13 year olds, private insurance	1 dose Tdap booster, 13 year olds, private insurance	1 dose Tdap booster, 13 year olds, public insurance	1 dose Tdap booster, 13 year olds, public insurance	1 dose Tdap booster, 13 year olds, public insurance
Sample mean	0.714	0.714	0.714	0.684	0.684	0.684
Tdap Mandate for Middle School Entry	0.118***	0.116***	0.118***	0.122*	0.143*	0.122*
	(0.0301)	(0.0358)	(0.0302)	(0.0642)	(0.0762)	(0.0641)
Immunization Insurance Mandate	-0.0574	-0.0605	-0.0561	-0.118	-0.0777	-0.119
	(0.0383)	(0.0521)	(0.0373)	(0.0725)	(0.0825)	(0.0769)
Tdap Mandate X Insurance Mandate	---	0.00311	---	---	-0.0450	---
		(0.0375)			(0.0650)	
Tdap Mandate X post-ACA preventive services mandate	---	---	-0.00645	---	---	0.00637
			(0.0424)			(0.0641)
R-Squared	0.185	0.185	0.185	0.176	0.176	0.176
N	15224	15224	15224	7238	7238	7238

* significant at 10%; ** significant at 5%; *** significant at 1%. See notes to Table 1 for details on the specification and control variables. All Sample means are calculated over the full period. Results are from linear probability models and use NIS-Teen sampling weights. Standard errors are clustered at the state level.

Appendix Table 16:
Effects of mandates on Tdap vaccine take-up, interacted with pharmacist authority

	(1) 1 dose Tdap booster	(2) 1 dose Tdap booster	(3) 1 dose MCV	(4) 1 dose MCV	(5) Initiated HPV vaccine	(6) Initiated HPV vaccine	(7) Completed HPV vaccine	(8) Completed HPV vaccine
Tdap mandate	0.142***	0.141***	0.0246	0.0268*	0.0490***	0.0479***	0.0393***	0.0508***
	(0.0171)	(0.0222)	(0.0159)	(0.0145)	(0.0149)	(0.0169)	(0.0108)	(0.0134)
Pharmacist authority	0.0441*	0.0557**	0.0475***	0.0531***	0.00540	-0.0446	0.00537	-0.0113
	(0.0251)	(0.0240)	(0.0161)	(0.0136)	(0.0260)	(0.0308)	(0.0107)	(0.0140)
Tdap mandate * Pharmacist authority	-0.0214	-0.0223	0.00140	-0.00173	0.00493	-0.0197	-0.0380**	-0.0471**
	(0.0242)	(0.0272)	(0.0173)	(0.0212)	(0.0224)	(0.0227)	(0.0164)	(0.0185)
N	111888	111888	111888	111888	55131	55131	55131	55131
R-squared	0.336	0.339	0.282	0.285	0.112	0.114	0.0653	0.0667
Linear state trends	N	Y	N	Y	N	Y	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. See notes to Table 1 for details on the specification and control variables. All Pharmacist authority is equal to 1 if pharmacists in the state have general or prescriptive authority, and are able to administer vaccines to children as young as 12 years of age. Sample means are calculated over the full period. Results are from linear probability models and use NIS-Teen sampling weights Standard errors are clustered at the state level.

Appendix Table 17:
Morbidity results are robust to log specification of outcome variable

	Population Morbidity		5-14 year old morbidity	
	(1)	(2)	(3)	(4)
	Log (pertussis cases +1)	Log (pertussis cases + 1)	Log (pertussis cases +1)	Log (pertussis cases +1)
Tdap mandate for Middle School entry	-0.303*	-0.229	-0.376**	-0.302*
	(0.171)	(0.170)	(0.183)	(0.179)
Log(population)	1.826	3.659	1.938	4.175
	(2.059)	(6.072)	(1.826)	(6.248)
R-squared	0.845	0.876	0.820	0.852
N	763	763	763	763
State linear trend	N	Y	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. Sample means are calculated over the full period. Results are estimated using disease incidence data from the CDC and are weighted by state population. These models include controls for state mandates for insurance coverage of well-child visits and vaccines; all child care/school vaccination mandates; state HPV and MCV policies; lagged pertussis incidence; state children's Medicaid/CHIP income eligibility thresholds; state unemployment rates; state demographic characteristics (fraction black, Hispanic, and other races, fraction of individuals with high school degree and with some college or more, and fraction below the federal poverty level); and state and year fixed effects. Standard errors are clustered at the state level.

Appendix Table 18:
Morbidity results are robust to alternative specification choices
Each entry is the coefficient on the Tdap mandate

	Population Morbidity		5-14 year old morbidity	
	(1)	(2)	(3)	(4)
1. Baseline Specification	-2.241*	-2.220	-8.986**	-8.242
	(1.262)	(1.543)	(4.318)	(5.479)
2. No weights	-2.501**	-2.650	-11.41**	-10.40
	(1.157)	(1.655)	(4.944)	(6.592)
3. Inclusion of VFC	-1.668*	-2.383**	-6.345**	-7.882***
	(0.867)	(1.073)	(2.687)	(2.917)
4. Inclusion of Section 317 control	-4.061**	-5.863**	-14.65**	-21.24**
	(1.944)	(2.394)	(6.734)	(8.627)
5. Inclusion of pharmacist scope of practice controls	-2.174*	-2.031	-8.717*	-7.381
	(1.276)	(1.595)	(4.382)	(5.652)
6. Omitting Controls in the Z vector	-2.319**	-2.525**	-8.309**	-8.914**
	(1.064)	(1.254)	(3.547)	(3.997)
State linear trend	N	Y	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. Sample means are calculated over the full period. Results are estimated using disease incidence data from the CDC and are weighted by state population. These models include controls for state mandates for insurance coverage of well-child visits and vaccines; all child care/school vaccination mandates; state HPV and MCV policies; lagged pertussis incidence; state children's Medicaid/CHIP income eligibility thresholds; state unemployment rates; state demographic characteristics (fraction black, Hispanic, and other races, fraction of individuals with high school degree and with some college or more, and fraction below the federal poverty level); and state and year fixed effects. Standard errors are clustered at the state level.

Appendix Table 19:
Heterogeneity in the Effects of Middle School Tdap Vaccination Requirements, NIS-Teen 2008-2013
Each entry is the coefficient on the Tdap mandate

	(1) 1 dose Tdap (direct effect)	(2) 1 dose MCV (spillover effect)	(3) Initiated HPV vaccine (spillover effect)	(4) Completed HPV vaccine (spillover effect)
1. Full sample				
Tdap mandate effect:	0.137***	0.0290*	0.0416***	0.0331***
	(0.0164)	(0.0148)	(0.0152)	(0.0107)
2. Public providers	0.186***	0.0542**	0.0587*	0.0381**
Tdap mandate effect:	(0.0233)	(0.0250)	(0.0309)	(0.0173)
3. Private providers	0.104***	0.0196	0.0478*	0.0344***
Tdap mandate effect:	(0.0172)	(0.0196)	(0.0244)	(0.0117)
4. Mixed provider type	0.220***	0.0256	0.0536	-0.000229
Tdap mandate effect:	(0.0213)	(0.0218)	(0.0331)	(0.0372)
5. Private insurance	0.118***	-0.0153	0.0199	0.0660***
Tdap mandate effect:	(0.0301)	(0.0294)	(0.0377)	(0.0193)
6. Public insurance	0.122*	-0.0539	0.0206	0.0421
Tdap mandate effect:	(0.0642)	(0.0565)	(0.0589)	(0.0447)

* significant at 10%; ** significant at 5%; *** significant at 1%. Columns 3 and 4 are restricted to females aged 13 between 2007-2013, and males aged 13 between 2011-2013. Rows 5 and 6 are restricted to individuals who were age 13 at the time of survey. See notes to Table 1 for details on the specification and control variables. All models include state trends.

Appendix Table 20:
Sensitivity of Vaccination Results to Choice of Controls, Sample, and Weights
Each entry is the coefficient on the Tdap mandate

	(1) 1 dose Tdap (direct effect)	(2) 1 dose MCV (spillover effect)	(3) Initiated HPV vaccine (spillover effect)	(4) Completed HPV vaccine (spillover effect)
2. Omitting Controls in X vector	0.137***	0.0290*	0.0399**	0.0325***
Tdap mandate effect:	(0.0161)	(0.0147)	(0.0151)	(0.0104)
3. Omitting Controls in Z Vector	0.144***	0.0633**	0.0354*	0.0148*
Tdap mandate effect:	(0.0184)	(0.0249)	(0.0184)	(0.00867)
4. Inclusion of VFC controls	0.136***	0.0278*	0.0415***	0.0315***
Tdap mandate effect:	(0.0161)	(0.0151)	(0.0154)	(0.0103)
4. Inclusion of Section 317 control	0.166***	0.0445**	0.0438*	0.0467*
Tdap mandate effect:	(0.0175)	(0.0203)	(0.0253)	(0.0244)
5. Inclusion of pharmacist scope of practice controls	0.136***	0.0264*	0.0413***	0.0351***
Tdap mandate effect:	(0.0173)	(0.0135)	(0.0145)	(0.00914)
4. Using landline weights in 2011	0.135***	0.0273*	0.0377**	0.0320***
Tdap mandate effect:	(0.0159)	(0.0156)	(0.0152)	(0.0108)
5. Using no weights	0.142***	0.0384**	0.0412***	0.0259**
Tdap mandate effect:	(0.0197)	(0.0150)	(0.0129)	(0.0110)
6. Restricted to sample that resides in state of birth	0.144***	0.0331*	0.0379**	0.0300**
Tdap mandate effect:	(0.0195)	(0.0167)	(0.0168)	(0.0122)

* significant at 10%; ** significant at 5%; *** significant at 1%. Columns 3 and 4 are restricted to females aged 13 between 2007-2013, and males aged 13 between 2011-2013. Rows 5 and 6 are restricted to individuals who were age 13 at the time of survey. See notes to Table 1 for details on the specification and control variables. All models include state trends.

Appendix Table 21:
Effect of Middle School Tdap Vaccination Requirements on Completion of HPV Vaccine Series Similar in Magnitude to Effect on Completion of 2+ doses of the Series, NIS-Teen 2008-2013

	(1)	(2)	(3)	(4)	(5)	(6)
	Initiated HPV vaccine series	Initiated HPV vaccine series	2+ Doses of HPV vaccine series	2+ Doses of HPV vaccine series	3+ Doses of HPV vaccine series	3+ Doses of HPV vaccine series
Tdap Mandate for Middle School Entry	0.0490***	0.0416***	0.0292**	0.0277*	0.0247***	0.0331***
	(0.0151)	(0.0152)	(0.0110)	(0.0144)	(0.00863)	(0.0107)
R-squared	0.111	0.113	0.0869	0.0887	0.065	0.066
N	57133	57133	57133	57133	57133	57133
Linear state trends?	N	Y	N	Y	N	Y

* significant at 10%; ** significant at 5%; *** significant at 1%. See notes to Table 1 for details on the specification and control variables. All columns are restricted to females who were age 13 between 2007-2013 and males who were age 13 between 2011-2013.